VLBI/Laser Intercomparison Project: Session 2

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Recent experiments are described which directly intercompare Very Long Baseline Interferometry (VLBI) with laser ranging to artificial satellites by measuring the vector lengths of the same intercontinental baselines. These experiments are part of the VLBI/Laser Intercomparison Project, a continuing task to assess the suitability of VLBI to various geophysical applications.

I. Introduction

Several systems are now under development by NASA and other agencies which should be capable of measuring baselines of several thousand kilometers with an accuracy of 5 cm, and baselines of several hundred kilometers to 3 or 4 cm:

Very Long Baseline Interferometry (VLBI)

Laser ranging to artificial satellites

Lunar laser ranging

Radio tracking of artificial satellites, which has already been implemented by the National Geodetic Survey (NGS) and the Defense Mapping Agency (DMA) with repeatability of 50 cm or better.

The great potential accuracy of the new systems presents both opportunity and challenge: the opportunity of measuring quantities important to civil engineering and navigation with great precision – land subsidence, movement along faults, regional deformation, and the rotation of the earth; but the challenge of making certain that the new systems really are delivering their rated accuracy, which exceeds all previous standards of comparison.

II. Project History

A VLBI/Laser Intercomparison Project has been established in order to compare VLBI techniques with laser ranging systems by conducting a series of measurements between common sites. A goal of the task is to assess the suitability of VLBI for geophysical applications. "Snapshot" experiments are being used to illustrate the key developments of the VLBI technique as it matures. The effort includes the co-location and intercomparison of VLBI with laser ranging systems.

The Intercomparison Project was established to ensure that VLBI development and the intercomparison with laser systems takes place in a timely and forthright manner. The Project also selects certain key tests to illustrate the development of VLBI. The validation experiments rely primarily on the hardware and software capability and related support associated with the DSN Advanced Systems (310 Program) and the DSN operational equipment development programs (311 and 312 Programs). No funding in the Intercomparison Project has been allocated for equipment development, equipment level analysis, installation or maintenance. This approach is analogous to flight project relationships to the TDA/DSN, where the necessary equipment capability is developed in a missionindependent mode. The Intercomparison Project supports data acquisition costs involved in validation experiments that are extraordinary to normal DSN operations. It also bears the direct costs incurred by non-DSN facilities in support of validation activity. The Intercomparison Project acquires necessary consumable items, and supports the data processing of validation experiments.

III. Project Experiments

The Project is divided into several Sessions, or groups of experiments, each of which concludes with a report assessing the performance of VLBI at a given stage in its development. Session I consisted of a series of measurements between pairs of antennas in the Goldstone complex, and was intended primarily to give an accurate picture of the state of VLBI development at the beginning of the Project, and to demonstrate organizational preparedness to perform more ambitious experiments. Session II, which is now being completed, is a direct comparison of VLBI with satellite laser ranging over intercontinental baselines.

This is the first real test of the application of space technology to geodesy, in which two independent systems of equally high precision have been used to measure the distance and orientation of the same two points separated by several thousand kilometers. If the results agree, they will encourage reasonable confidence that both systems are working to their expected level of accuracy. Further, more rigorous tests of accuracy will then be justified.

The Session II experiments were designed to intercompare not only VLBI with laser but results from different kinds of VLBI hardware, called Mark I and Mark II. Using either Mark I or Mark II, the observing strategy is to observe each radio source simultaneously from all stations for several minutes. Mark I switches among five channels at X-Band frequencies with an instantaneous bandwidth of 360 kHz, recording on ordinary computer tape, 3 min per tape. Mark II switches among 3 channels at X-band frequencies with an instantaneous bandwidth of 2 MHz, on video tape, each tape containing about one hour of data. The Mark I and Mark II data were recorded simultaneously at the observing stations. It is not practical to take VLBI and laser data strictly simultaneously; but the experiments were designed to be completed over a few months, with the several VLBI experiments interlaced in time with the laser measurements, so that the possibility that earth crustal movement might create an unverifiable difference between the VLBI and laser determinations of the baselines might safely be ruled out.

Accordingly, three mobile laser satellite (MOBLAS) tracking units were deployed at the Haystack Observatory, the Owens Valley Observatory, and at Goldstone (DSS 14). Four months were required to maximize the possibility of three station simultaneous observations. During December, January, and February, JPL, GSFC, and the group at Haystack cooperatively scheduled MKI/MKII experiments at Goldstone, Haystack, and Owens Valley. MOBLAS systems occupied sites at Goldstone, Haystack, and Owens Valley from November 1, 1977, to March 31, 1978. JPL coordinated pad requirements at Owens Valley and provided additional equipment (BWS – Band Width Synthesis Units) to Haystack and Owens Valley in order to operate the MKII system. JPL/GSFC/Haystack technical personnel cooperated to define a mutually agreeable observing strategy. There were three VLBI observing sessions: December 13 through 15, 1977, and January 13 through 16 and February 24 through 26, 1978. JPL was responsible for providing water vapor radiometer support at both Goldstone and Owens Valley. The Haystack Observatory provided water vapor radiometer support at Haystack. The Haystack 37-m antenna was equipped for simultaneous S/X operation with system temperatures of 150 K at S-band and 70 K at X-band, hydrogen masers, phase calibrators, Mark I and Mark II recorders, and a water vapor radiometer. DSS 14 was operated in the following configuration: S- and X-band receivers, 40 MHz synthesized bandwidth, 20-30 K system temperature at zenith, 4 Mb/s record rate, no phase/cable calibration, and hydrogen (H) masers for the last two experiments. A water vapor radiometer was available at Goldstone for the last two experiments. The Owens Valley 39-m antenna was equipped with S- and X-band receivers, phase and cable calibration, H-maser, water vapor radiometer, and Mark I and Mark II recorders.

Of the three mobile laser satellite tracking units, MOBLAS vans 1 and 3 were already equipped with high-powered green lasers delivering a pulse 6 ns (180 cm) in length, and measuring range with a precision of approximately 25 cm. The MOBLAS 2 unit, which was deployed to Owens Valley, was equipped with a similar laser, so that all stations could simultaneously range to LAGEOS, a satellite in a high earth orbit. Other satellites which are routinely tracked by MOBLAS units include Beacon Explorer 3, GEOS-1, GEOS-3, Starlette, Timation, and NTS-2. Since the Satellite Laser Ranging System was committed to support SEASAT from May 1978 at least through 1980, and will not be available again at sites where its performance can readily be assessed, OTDA and OSTDS jointly agreed that even a limited intercomparison with the VLBI technique would be worthwhile.

For MOBLAS, the measurement objective was ±10 cm precision for the shorter baseline (Goldstone/Owens Valley) and ±50 cm on the longer baseline (Haystack/Goldstone), based on the assumption that at least 30 passes could be measured simultaneously from all sites during the several months' occupation. A combination of bad weather and equipment failure may have degraded the laser satellite data from the goal.

A third system which has been deployed at all three sites is the satellite doppler positioning system developed by the Defense Mapping Agency (DMA) and now regularly used by the National Geodetic Survey (NGS). The NGS standard field procedure is to observe 40 passes of suitable satellites of the Navy Navigation Satellite System, also known as the TRANSIT system. The number of passes is larger than that expected to be observed by the MOBLAS system in the Intercomparison Project experiments, even though the NGS site occupation time is shorter, primarily because radio data can be acquired even in cloudy weather. Doppler positions are acquired by the point positioning system, in which the orbit of the satellite is taken from an ephemeris and not adjusted. The NGS uses the most precise satellite ephemerides available from the DMA, which are produced using the NWL 10E gravity model and the NWL 9D coordinate set for the tracking stations providing data from which the ephemerides are generated. Typical precision of a satellite doppler position is 0.5 m in latitude and height, and about 1 m in longitude. The NGS assumed responsibility for the local surveys, which tied together the VLBI antenna, the MOBLAS unit, and the satellite doppler geodetic control point at each of the three sites.

The purpose of Session II has been to provide an accurate "snapshot" of VLBI and MOBLAS performance. There were no preset requirements of accuracy to be met. A system is to be judged a failure in the Haystack/OVRO/Goldstone experiments in any of three, but only three, catastrophic eventualities:

(1) Failure to acquire data over the 4-month interval.

(2) Generation of inconsistent data.

(3) Generation of data in significant disagreement with conventional geodesy, that is, 10 or 20 m in error between Haystack and Goldstone, or a meter or so in error between Goldstone and OVRO.

Nevertheless, based on previous performance, we expect the VLBI data on the intercontinental lines to be of 20 – 30 cm quality.

The VLBI data from Session II are now being cross-correlated and seem satisfactory. A project review in which the VLBI, laser, and doppler satellite results will be presented and compared is scheduled at NASA Headquarters in July 1978.

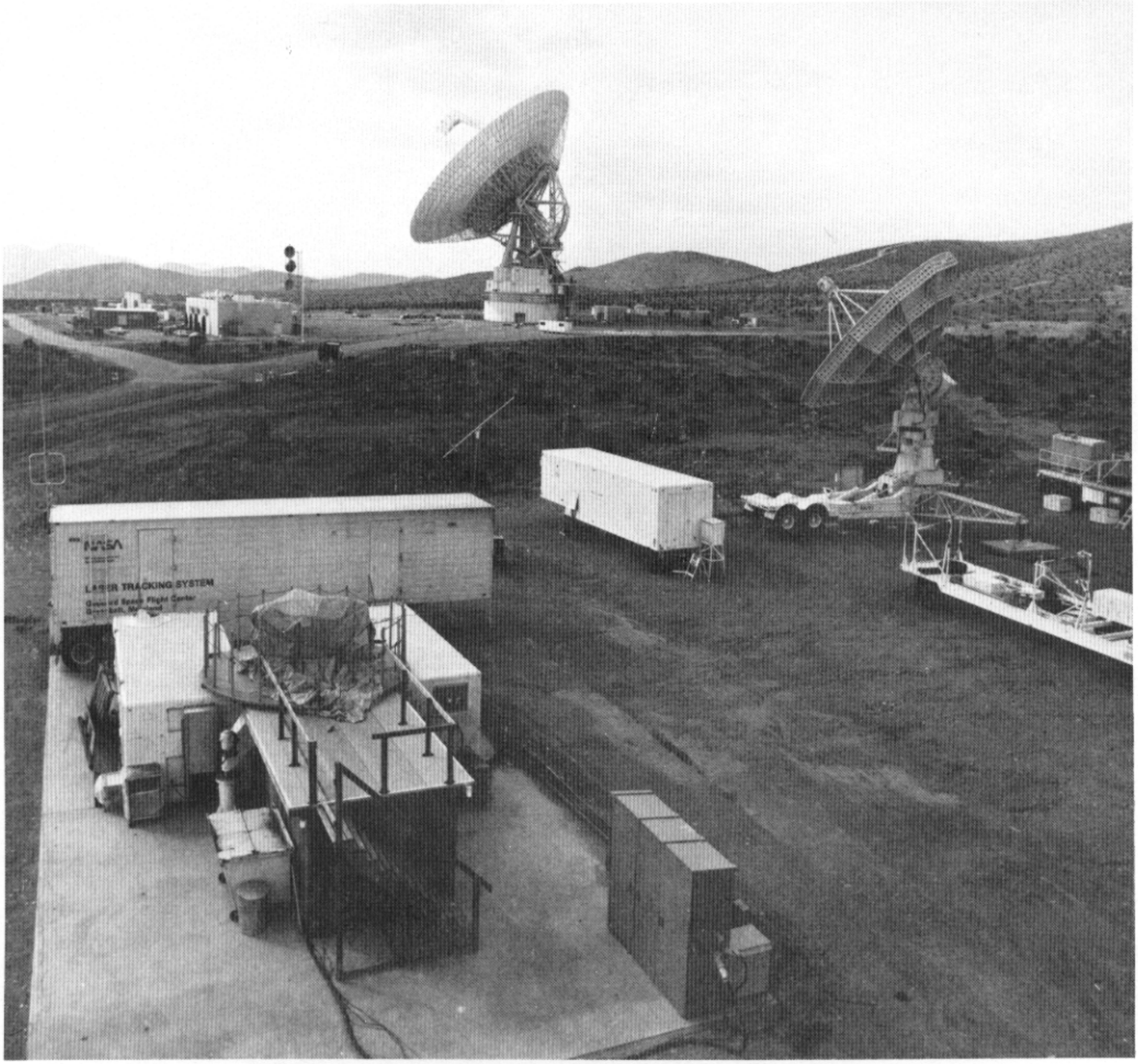

Fig. 1. A MOBLAS satellite laser ranging unit is brought to Goldstone as part of the VLBI/Laser Intercomparison Project. DSS 14 is in the background (top, center) and the ARIES 9-m transportable antenna on the right.